P2 THROUGH NANOTECHNOLOGY
SEPTEMBER 25-26, 2007

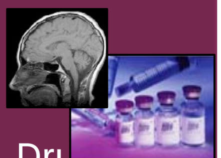
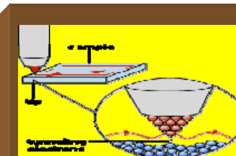
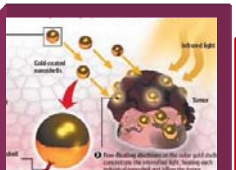
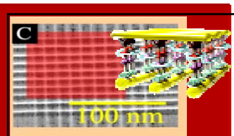
Nanotechnology and Pollution Prevention: An Exploratory Example

E. Clayton Teague
Director
National Nanotechnology Coordination Office
National Science and Technology Council

Pollution Prevention Through Nanotechnology Conference
Arlington, VA * September 25, 2007

Widespread Application Areas for Nanotechnology

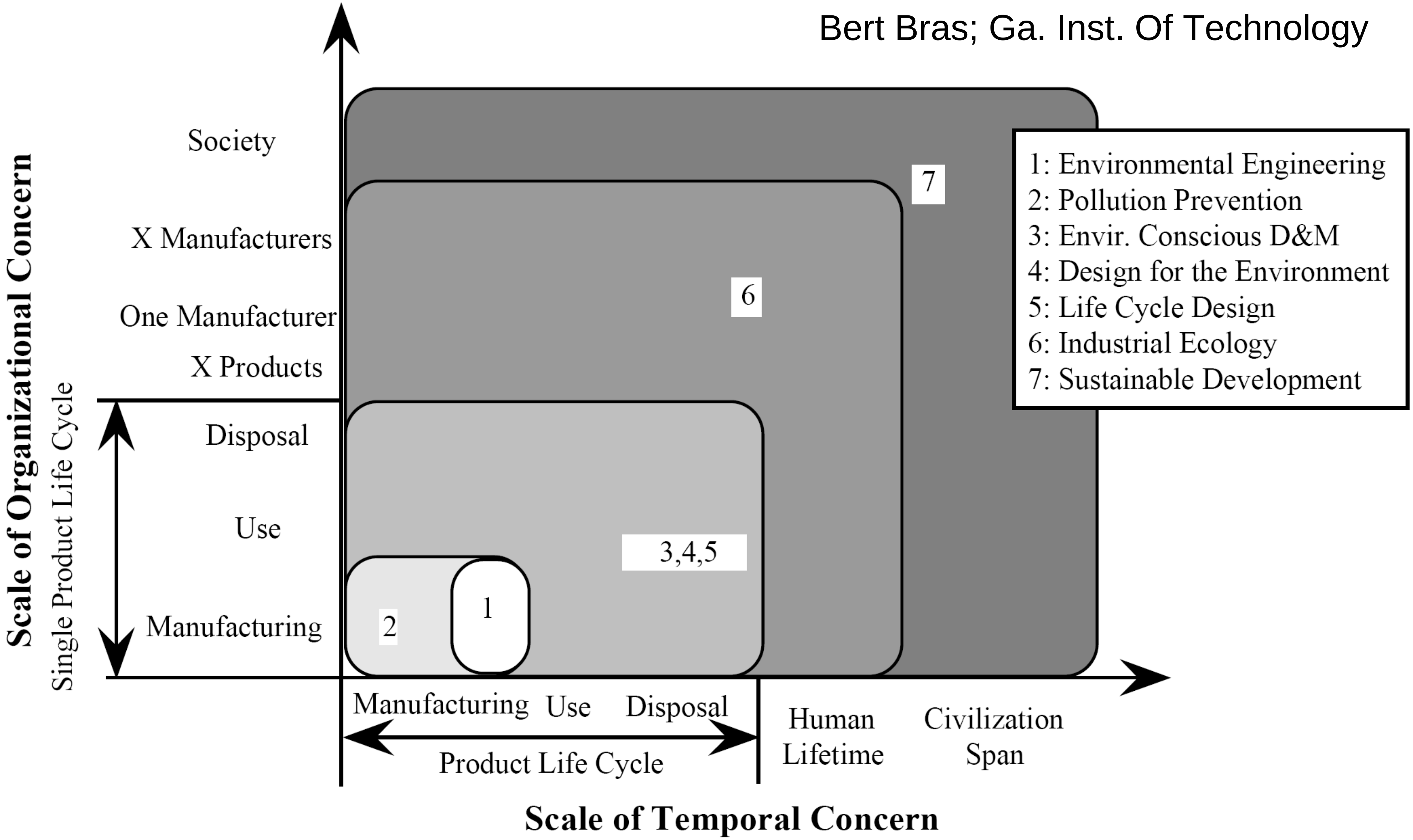
In Part, from R. Tomellini

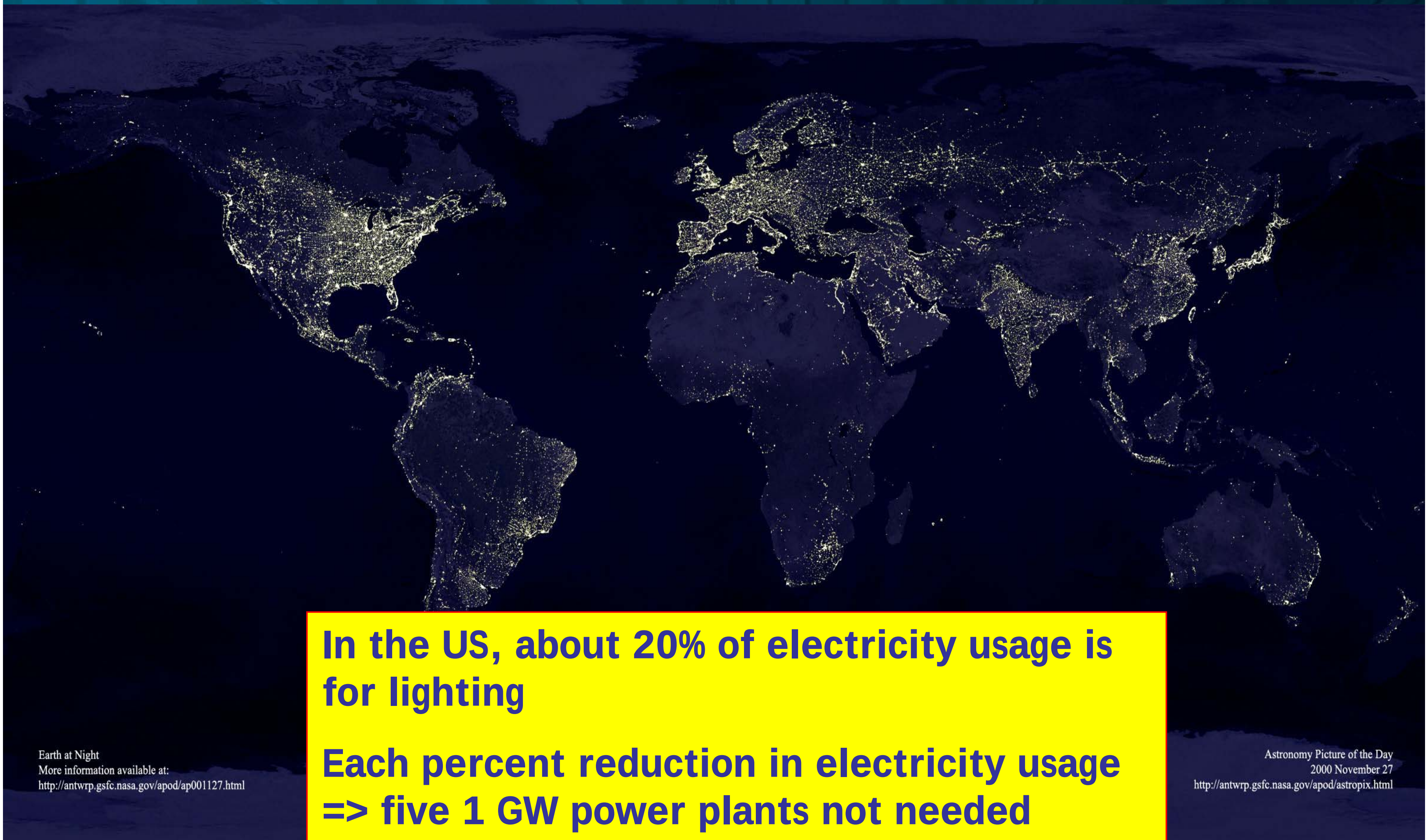
Medicine and Health	Information Technology	Energy Production Storage Transmiss. Use	Materials Science	Water and the Environ-ment	Instruments	Food
 Drug delivery	 GMR Hard Disk	 Hydrogen Fuel Cells	 Lightweight & strong matls.	 Remediation methods	 Tunneling microscopy	Packaging
 Treatments for Cancer	 Molecular Switches	 Solar Cells	 City-Sized Skyscrapers	 "Smart" Membranes	 Nano Manipulators	Pathogen Sensors

Expected to impact virtually all technological sectors as an "enabling" or "key" technology

Scope of Environmental Systems Issues

Bert Bras; Ga. Inst. Of Technology

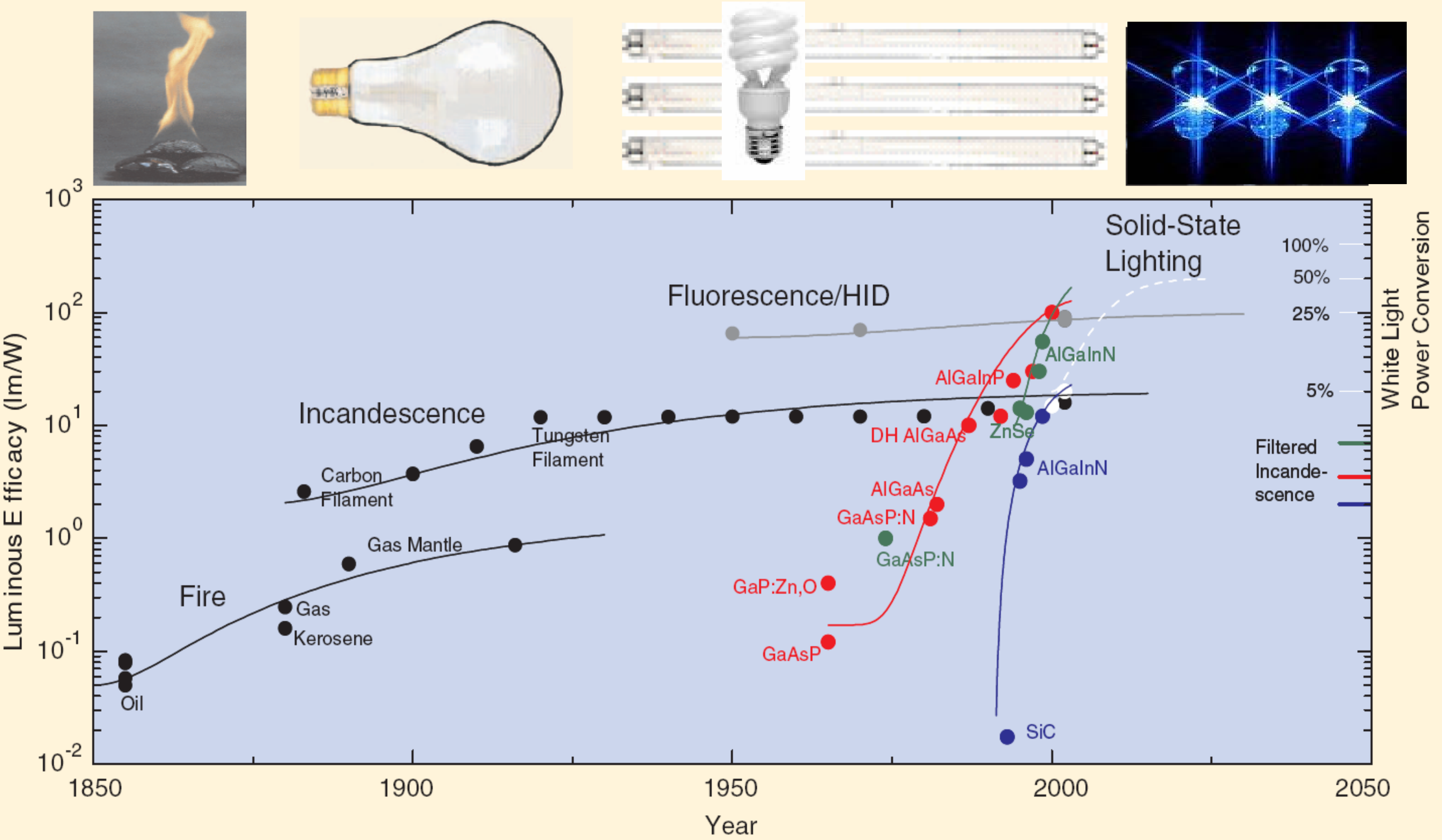




In the US, about 20% of electricity usage is for lighting

Each percent reduction in electricity usage => five 1 GW power plants not needed

200-year Evolution of Luminous Efficacy for Various Lighting Technologies



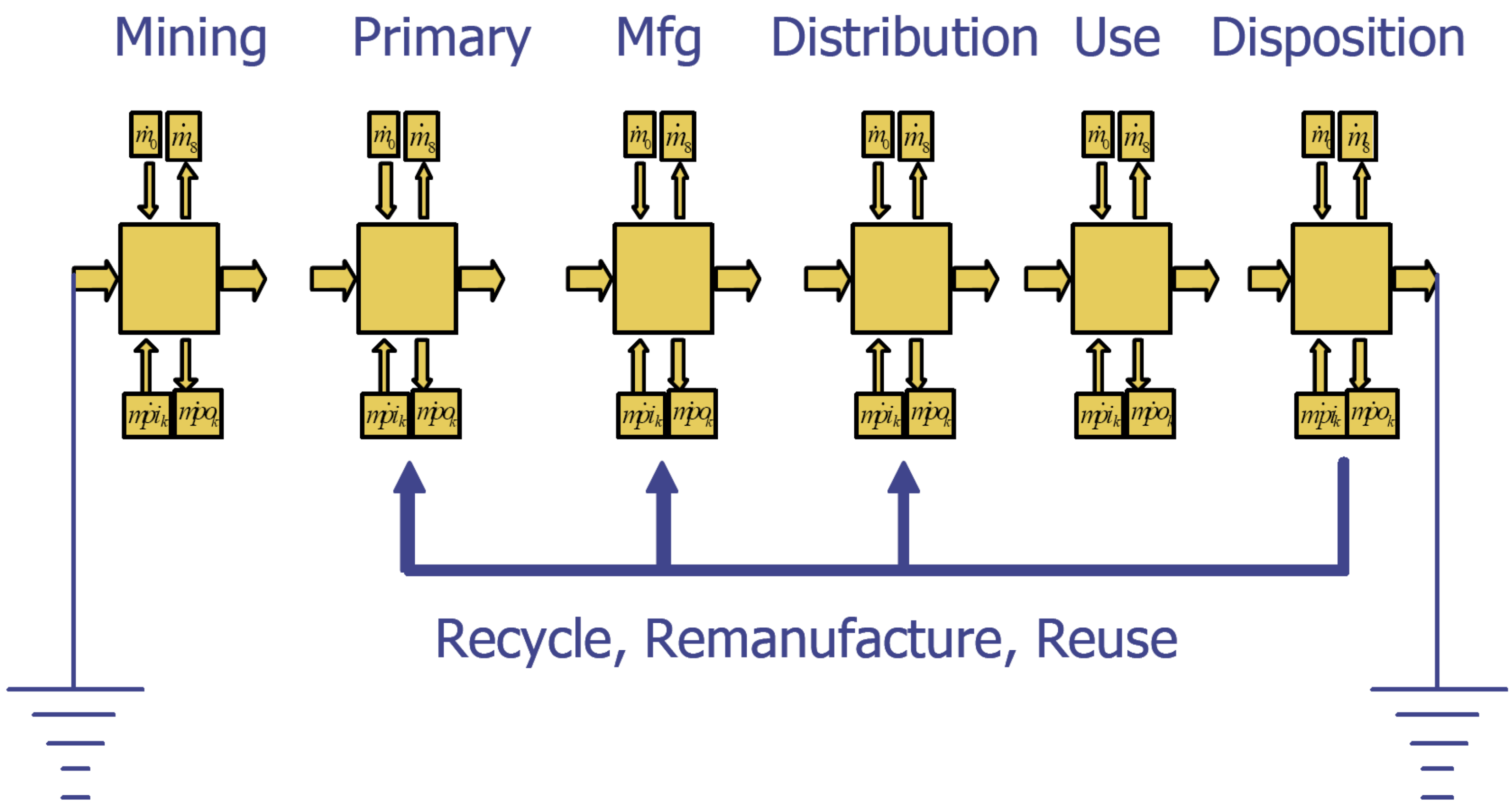
Efficiency and Lifetime Comparisons

	Efficiency (lumens/ watt)	*Expected Lifetime (hours)*
Standard general service incandescent	14	1,000
Compact screw-in fluorescent	55	10,000
White light solid state light emitting diodes	70-150*	20,000 – 70,000

***Cree, Inc. announced 9/13/07 R&D results of 129 lumens per watt for a cool-white LED and 99 lumens per watt for a warm-white LED**

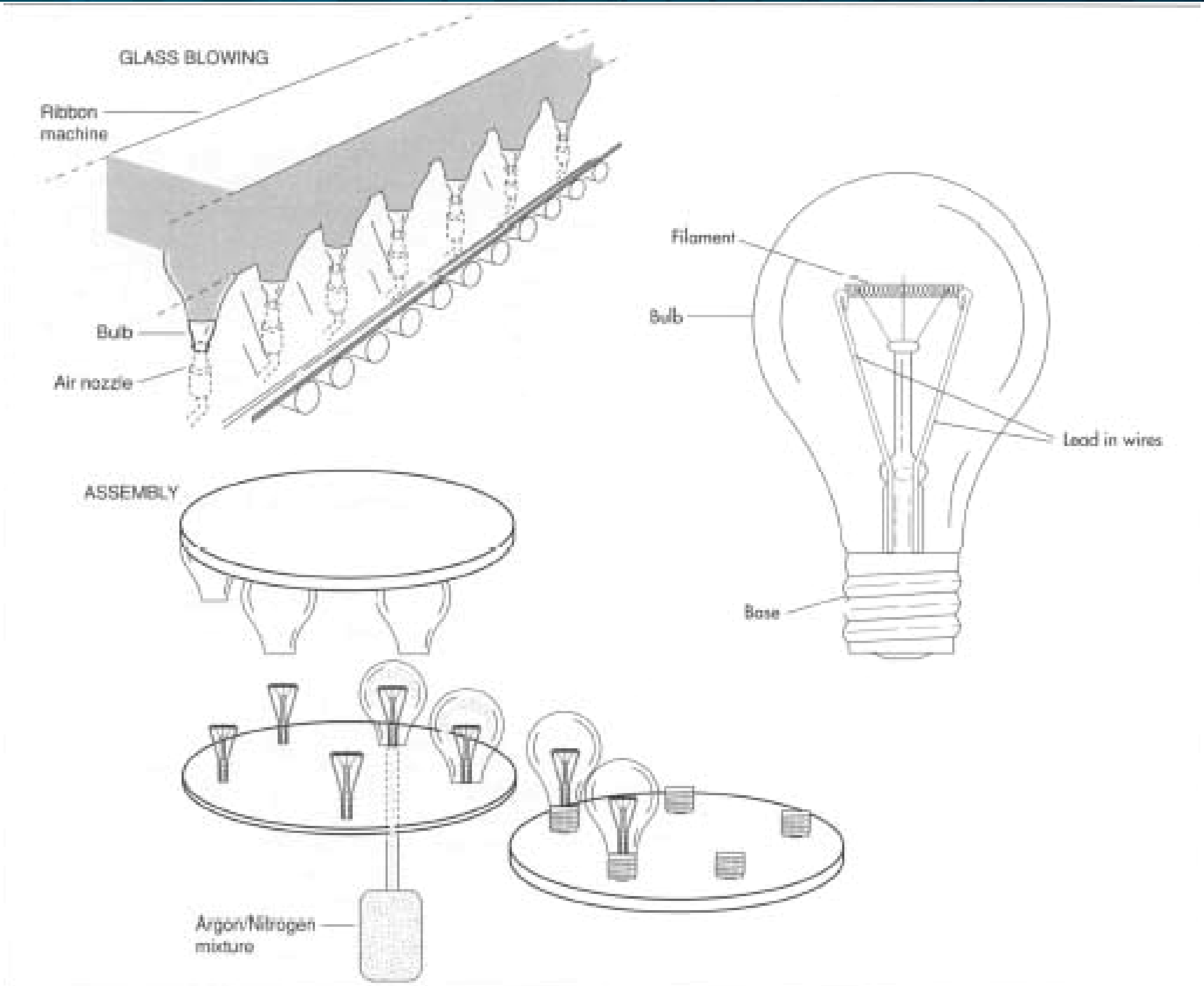
"Energy Savings Potential of Solid State Lighting in General Illumination Applications"
DOE Office of Energy Efficiency and Renewable Energy - November 2003

Product Life Cycle Material Flows



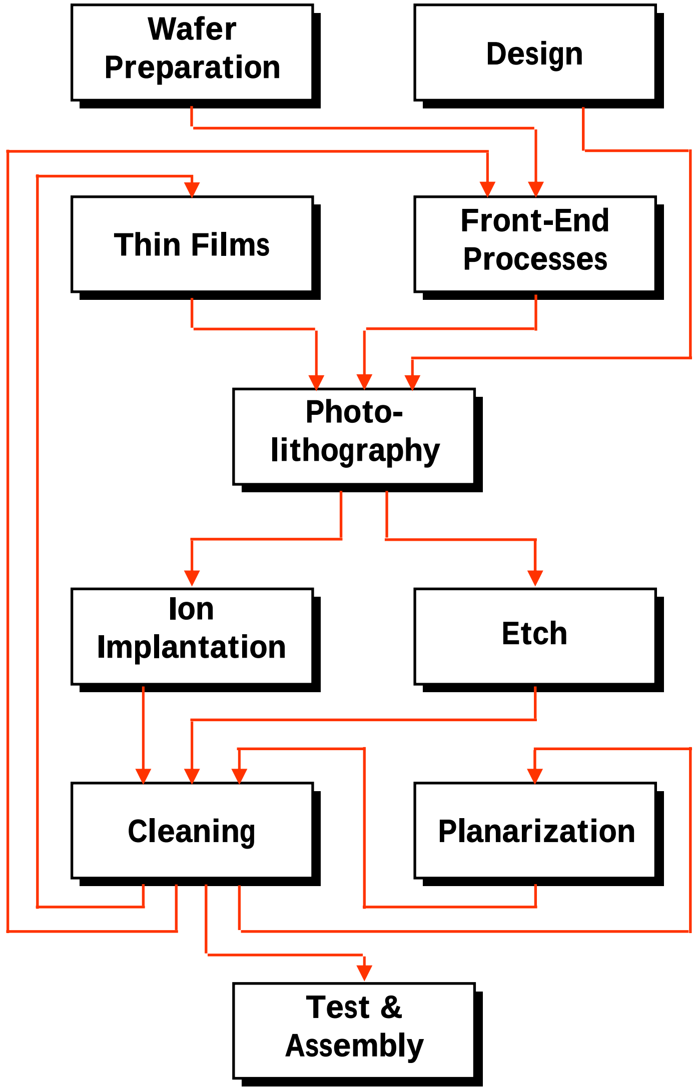
T. G. Gutowski; December 2004;
Handbook of Mechanical Engineering

Mfg. Incandescent Bulb - Simple

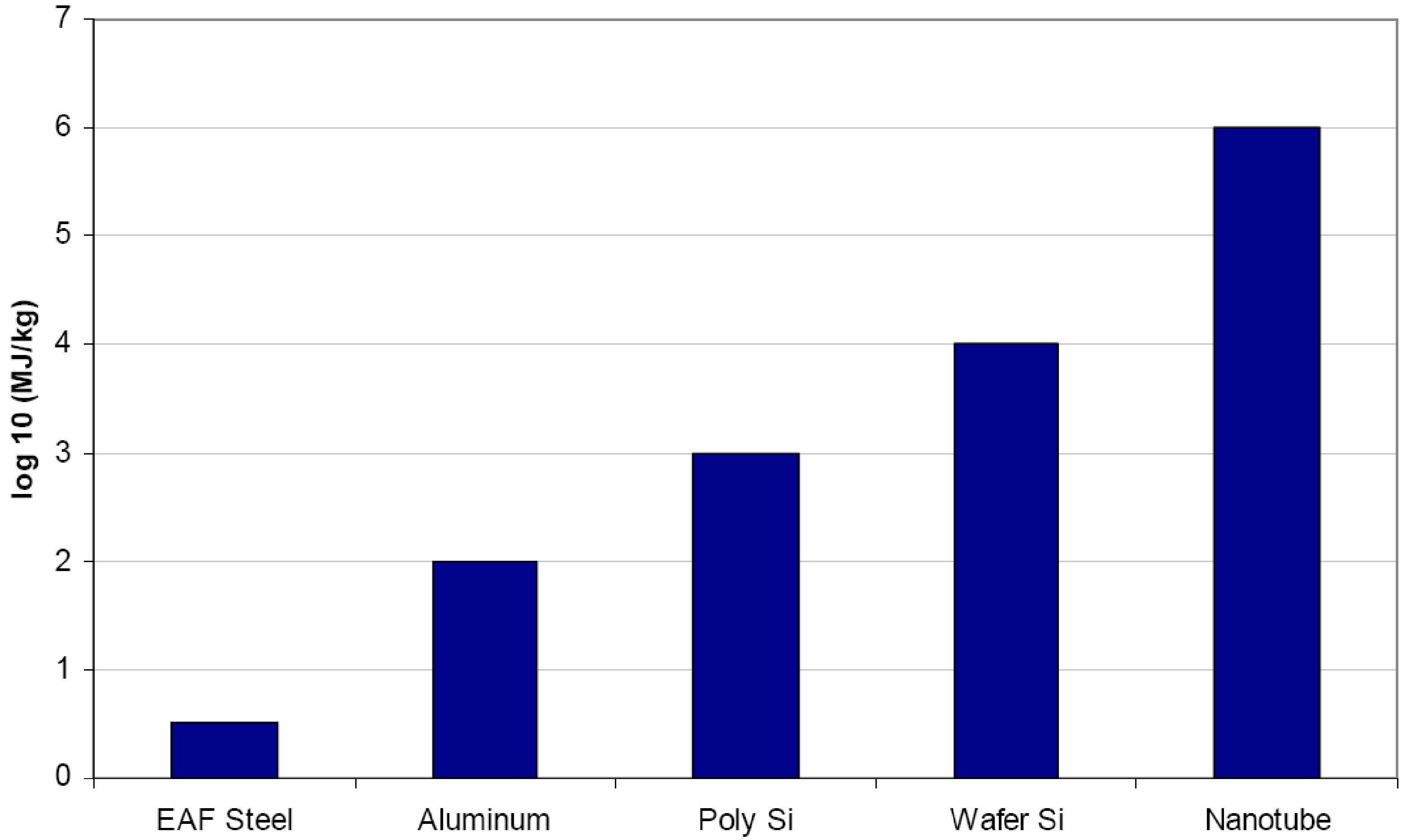


Semiconductor Manufacturing Processes - Complex, Energy Intensive

Mass of 32 MB DRAM Chip	2 grams
Total chemical inputs	72 g/chip
Total fossil fuel inputs	1,600 g/chip
Total water use	32,000 g/chip
Total elemental gas use	700 g/chip



Electrical Energy Requirements to Produce 1 Kilogram of Five Materials.

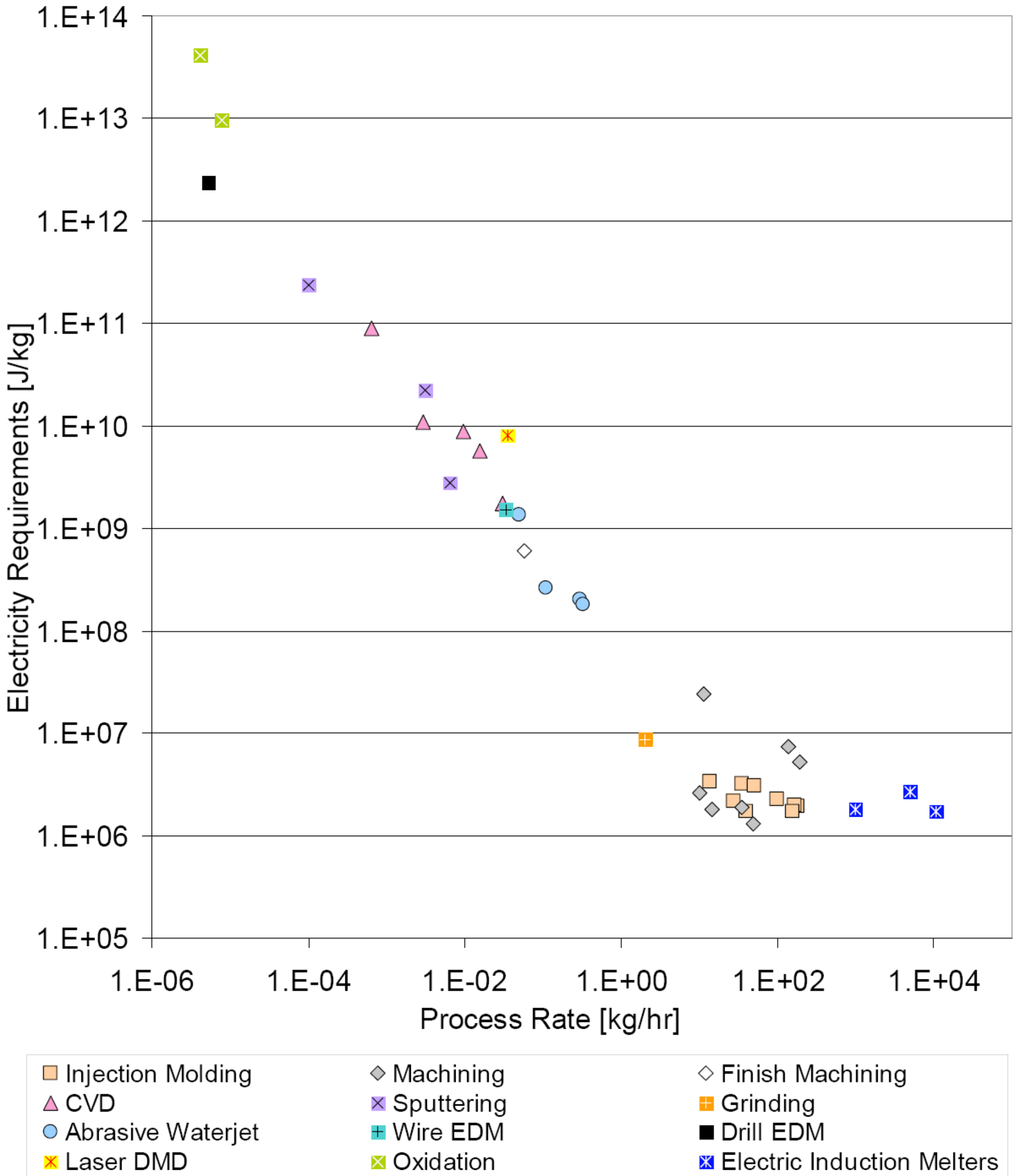


Electric Arc Furnace

Energy Requirements Increase for High Tech, Smaller Feature Manufacturing Processes

TG Gutowski, J Dahmus, A Thiriez

Proc. CIRP Conf. on Life Cycle Eng. Leuven, 2006



Graedel's Environmentally Responsible Product Assessment Matrix

	Life Cycle Stage				
Environ-mental Stressor	*Pre-manufacture*	*Product Manufacture*	*Product Delivery*	*Product Use*	*Disposition*
Materials Choice					
Energy Use					
Solid Residues					
Liquid Residues					
Gaseous Residues					

Graedel's Environmentally Responsible Product Assessment Matrix

Incandescent Light Bulb

	Life Cycle Stage				
Environ-mental Stressor	*Pre-manufacture*	*Product Manufacture*	*Product Delivery*	*Product Use*	*Disposition*
Materials Choice	(V [illegible]	[illegible]	[illegible]	[illegible]	4
Energy Use	(Gla [illegible]	[illegible]	[illegible]	[illegible]	4
Solid Residues	3	3	3	1	3
Liquid Residues	3	3	3	1	4
Gaseous Residues	3	3	3	1	4

Score

*GE Developing Incandescent Light Bulb that promise to match CFL's Efficiency * Feb 24 2007*

Graedel's Environmentally Responsible Product Assessment Matrix

Compact Fluorescent Light Bulb

	Life Cycle Stage				
Environ-mental Stressor	*Pre-manufacture*	*Product Manufacture*	*Product Delivery*	*Product Use*	*Disposition*
Materials Choice	2 (Hg, glass, phos.)	2 (Fairly complex)	3	3	2 (Hg, phos.)
Energy Use	2	2	3	[illegible]	2 (Cpx. Recy)
Solid Residues	2	[illegible]	3	3	2
Liquid Residues	[illegible]	[illegible]	3	3	3
Gaseous Residues	2	3	3	3	3

Score = 63

Graedel's Environmentally Responsible Product Assessment Matrix

White Light Emitting Diode Based Light Bulb

	Life Cycle Stage				
Environ-mental Stressor	*Pre-manufacture*	*Product Manufacture*	*Product Delivery*	*Product Use*	*Disposition*
Materials Choice	2 (Adv. Mtls.<<qty)	2 (Complex mfg.)	4	[illegible]	2
Energy Use	2 (Pure Mtls.)	2	4	4	3
Solid Residues	2	2	4	4	2
Liquid Residues	2	[illegible]	4	4	3
Gaseous Residues	3	3	4	4	3

Score = 75

Hg Pollution From Operation & Disposal of Different Technology Light Bulbs

	CO_2 emissions from power plant per 1000 lumen-hour of operation	Hg emissions from power plant per 1000 lumen-hour of operation	Power Plant Emissions of CO_2 for 25.5 Mlh 100 W Incd. For 5 yrs at 10 h/day	Number of bulbs X Mass of Hg per bulb	Power Plant Emissions of Hg for 25.5 Mlh* 100 W Incd. equivalent for 5 yrs at 10 h/day	Total Hg to environment for 5 years operation
Standard general service incandescent	**43 g/klh (grams per 1000 lumen-hr)**	**0.3 ug/klh**	**1100 kg**	**18 x 0**	**7.6 mg**	**7.6 mg**
Compact screw-in fluorescent	**11 g/klh**	**0.07 ug/klh**	**280 kg**	**2 x 4 mg of Hg**	**1.8 mg**	**9.8 mg**
White light solid state light emitting diodes	**6 g/klh**	**0.04 ug/klh**	**153 kg**	**1 x 0 Hg (bound Ga + S, Se, N)**	**1.0 mg**	**1.0 mg**

*Assumes 4 micrograms Hg emitted per kwh energy generated by power plant – From EPA MACT floor limits

Conclusions from Simplified LCA

- Even partial and simplified LCA is difficult – requiring significant time to track down quantitative information and data
  - Each material in product needs to be tracked through lifecycle
- Very informative with often surprising results
- Nanotechnololgy offers major opportunities to:
  - Choose materials of lesser toxicity
  - Use smaller quantities of materials to achieve function
  - Simplify raw material refining and mfg. processes
  - **But**, may also increased energy per unit processed mass
  - Realize higher energy efficiency devices with resultant minimized environmental impact

How and Where in the Product Life Cycle Can Nanotechnology have an Impact?

	Life Cycle Stage				
Environ-mental Stressor	*Pre-manufacture*	*Product Manufacture*	*Product Delivery*	*Product Use*	*Disposition and/or Recycling*
Materials Choice	Less toxic mtls Less qty. mtls	Less waste; directed self-assembly	Point of use manufacture	Engineered to be safe	Engineered for bio compatibility
Energy Use	Less waste of energy	Less waste of energy and mtls	Compact realization of function	High efficiency of realized function	“
Solid Residues	Less waste				
Liquid Residues	Less waste				
Gaseous Residues	Less waste				